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PROPAGATION OF SOUND GENERATED ON THE ICE SURFACE INTO WATER

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ABSTRACT

One of the difficulties in taking underwater acoustic measurements at arctic ice camps is avoiding contamination of the measurements with camp-generated noise. To minimize this problem, investigators sometimes use a surface-laid cable system to place hydrophones well away from the camp. But how far from an ice camp must hydrophones be to ensure that camp generated high-frequency interference (>1 kHz) is negligible? To answer this question, simulated camp noise was propagated from a source on top of the ice into the water below. Short-range measurements were then taken to locate the shadow zone under the ice where the acoustic energy from the source is negligible compared with the ambient noise field. This shadow zone was compared with sound propagation models that accounted for the refraction and absorption losses in the sea ice and in the water below. Inputs to the models were then adjusted to simulate different environmental conditions and longer ranges. Finally, conservative formulae were developed for determining the range and depth of hydrophone placement for a given reduction in the sound level from the source on the surface.

I. INTRODUCTION

Measurement of the natural underwater ambient noise in the Arctic is necessary to evaluate the performance limit of sonar/acoustic systems in that environment. Unfortunately, man-made camp noises such as those caused by power generators, walking, snowmobiles, etc., propagate through the ice and into the water and dominate the ambient noise at or near the camp. To avoid contamination from such sources, noise measurement hydrophones, connected to recording equipment in the camp via surface cables, are sometimes placed well away from the camp. However, the appropriate distance is not known. The goal of this study is to determine, for a given deployment depth, the minimum range to place a hydrophone in order to get a desired reduction in the camp-generated noise received.

The approach taken was first to simulate camp noise in the field by propagating sound from a source on top of the ice into the water below. The propagation was then measured, and the results were compared with predictions by two sonar models, the Generic Sonar Model (GSM)[1] and the Seismo-Acoustic Fast field Algorithm for Range-Independent environments (SAFARI).[2] After confidence was gained in the ability of the models to simulate a severely refractive acoustic environment, a wide range of sound speed profiles in the ice (representing a variety of arctic environmental conditions) was then input to the models to compute the sound pressure field at longer ranges. The pressure fields obtained were compared, and the one with the least reduction in the noise level as a function of range was used as a guide for developing the noise reduction formulae to use in placing hydrophones away from an ice camp.

II. SIMULATION MODELS

A brief description of the two models used is given here. Details are given in the references cited. Both models start out with the wave equation for horizontally stratified and cylindrically symmetric media. GSM then expands the equation into integrals of multipath rays.[3] Each integral leads to a so-called generalized ray—hence the name "generalized ray theory" for this technique. Given a stratified medium and known boundary reflection coefficients, the sound pressure level at any depth and range is then computed as the sum of the integrals of the pressure of the multipath rays between a given source-receiver geometry. SAFARI, on the other hand, applies a series of integral transforms to the wave equation and reduces it to a system of linear equations.[4–6] These are then solved numerically within each layer for the field coefficients that satisfy the boundary conditions at the interfaces. The pressure is then determined by the evaluation of the inverse transformation. In contrast to GSM, SAFARI recursively calculates the pressure fields so that the boundary conditions at the interfaces are satisfied.

Thus we have two predictive models based on different approaches to the solution of the wave equation. Bear in mind, however, that the purpose here is to use the models to help us gain insight into the problem, not to validate the models. Comparing the measurement with the model simulations merely serves to illustrate the applicability of the models to the problem at hand.

III. EXPERIMENTAL APPROACH

The experiment was carried out on flat ice 2.1 m thick at an ice camp in the Beaufort Sea in the spring of 1988. The sound at the surface was generated manually by dropping a steel ball from a fixed height onto the end of a short piece of metal rod frozen vertically into the ice. The ball was 6.4 cm in diameter. A 7.3 cm i.d. cardboard tube 43.2 cm in length was used as the guide during the fall. The anvil was a 2.54 cm diameter steel rod 6.4 cm in length with a thin layer of cork wrapped around its side wall. The cork was intended to acoustically decouple the side wall from the ice so that most of the acoustic energy was sent out only from the lower end of the rod. For each drop, the tube was centered over the rod, and the ball was placed on the rim of the tube and then given a slight push to initiate its fall. Because of the 0.9 cm clearance between the ball and the inside of the tube, the ball did not strike the rod squarely at the center every time. In the worst case, it would have struck ~0.5 cm off-center, while still making a square contact. The ball rebounded after each drop, the second contact typically occurring ~230 ms after the first.

At ~10 cm away from the anvil, an ITC1089 transducer, herein designated hydrophone #1, was frozen in the ice to pick up the generated acoustic pulse for use as an oscilloscope trigger. A second ITC1089 (hydrophone #2) was used as the receiver and positioned at different ranges and depths in the water to map the sound field generated. Signals received by hydrophones #1 and #2 were digitized on a Nicolet oscilloscope and stored on floppy disks. Measurements were continued at increasing range until the signal-to-noise ratio became so poor that a signal could no longer be seen.

IV. EXPERIMENTAL RESULTS

Figure 1 shows a complex waveform generated by the ball striking the anvil, as received by hydrophone #1 in the ice, and its corresponding power spectrum. Examination of many generated waveforms shows that they usually reproduced well but with some variations in the amplitude. Figure 2 shows a waveform received by hydrophone #2 in the water and its corresponding power spectrum. To compare the sound level measured at different locations, we used the same frequency component because the signals are wideband. The 7 kHz component was used since the spectra peak there and are therefore easier to read. Furthermore, to simulate the condition of a constant source level, the level at hydrophone #1 was used to provide a source level correction which was then applied to the received levels at hydrophone #2. The corrected levels relative to an arbitrary fixed value are shown in a range vs depth plot in Figure 3. Values considered to be in the background noise are designated with an asterisk.

The figure also shows an elementary ray diagram illustrating the severe refraction and the shadow zone resulting from the sharp gradient in the sound speed profile (SSP) at the ice-water interface. It can be seen that the agreement is fairly good at ranges less than 8 m. Beyond that range, however, the decrease in the measured levels does not seem to follow the ray spacings. This is not surprising, as the classical ray theory cannot predict the sound intensity in a shadow zone.

However, SAFARI and GSM (to a lesser extent) are able to cope with shadow zones. The SSP in Figure 3 was therefore input into both models to obtain a map of sound levels in the range-depth plane, just as was done for the measurements. The standard deviation in the difference of the sound levels is 3.4 dB between the measurements and the GSM simulation and 5.0 dB between the measurements and the SAFARI simulation. The relatively small standard deviations indicate that both models do a reasonable job of modeling at short ranges.

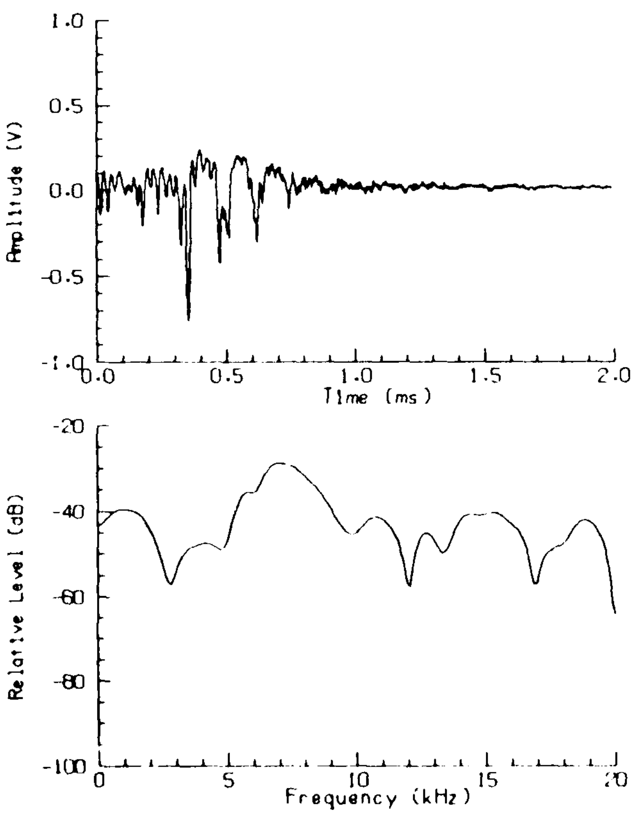

Figure 1. A typical waveform received at hydrophone #1 in ice and its power spectrum.

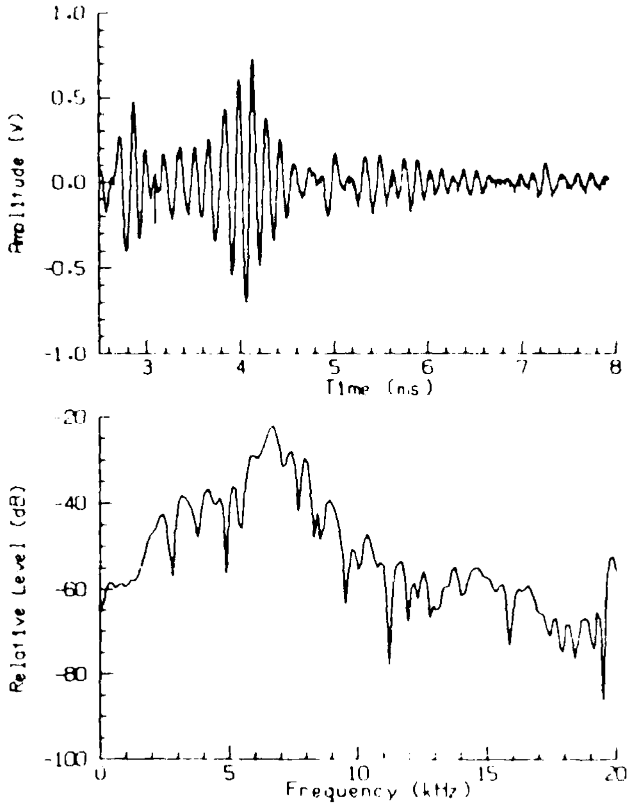

Figure 2. Waveform received at hydrophone #2 in water and its power spectrum.

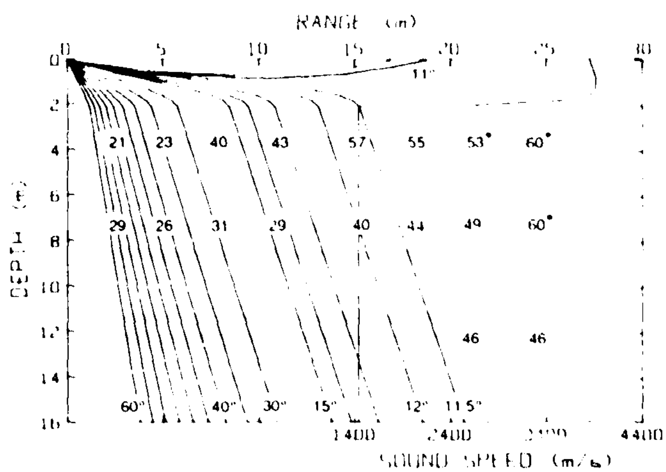

Figure 3. Measured sound levels and ray trace. Asterisks indicate noise.

V. SIMULATION FOR LONGER RANGES

Since the performance of both models at short ranges for an SSP with a severe gradient appeared to be satisfactory, it was assumed that the results at longer ranges would also be satisfactory. The task then was to find an SSP that would yield, for a noise source on the surface of the ice, the least reduction in the sound level as a function of range and depth. That SSP was defined as the worst case. The simulation result for the worst case was used because it guaranteed that the artificially generated noise would be reduced by at least the desired amount at the range and depth of interest.

To find the worst case SSP for the purpose, simulation runs were made using many SSPs. The SSPs, representing a variety of environmental conditions, are shown in Figure 4. The SSP in each case is derived by applying appropriate models of temperature, salinity, and density in the ice to elasticity theory. The temperature model used assumed a linear profile between the air and the water temperatures. The salinity model for the first-year ice is a version of a continuous-line model by Maykut[7] that has been modified to have three segments: one for the surface, one for the mid-column, and one for the skeletal layer. For the multiyear ice, a two-segmented profile is used. The lower segment is the same as the one for the skeletal layer in the first-year ice because the skeletal layer of the multiyear ice is subjected to the same variables. The upper segment starts with a salinity of 0‰ and increases linearly to match that at the skeletal layer boundary. The density model is again based on Maykut's study. The SSP in the water is derived from a CTD cast taken in 1988 and is typical of the Beaufort Sea profiles. In addition to these SSPs, an idealized version with zero gradient both in the ice and in the water is used for the purpose of comparison. Since the worst

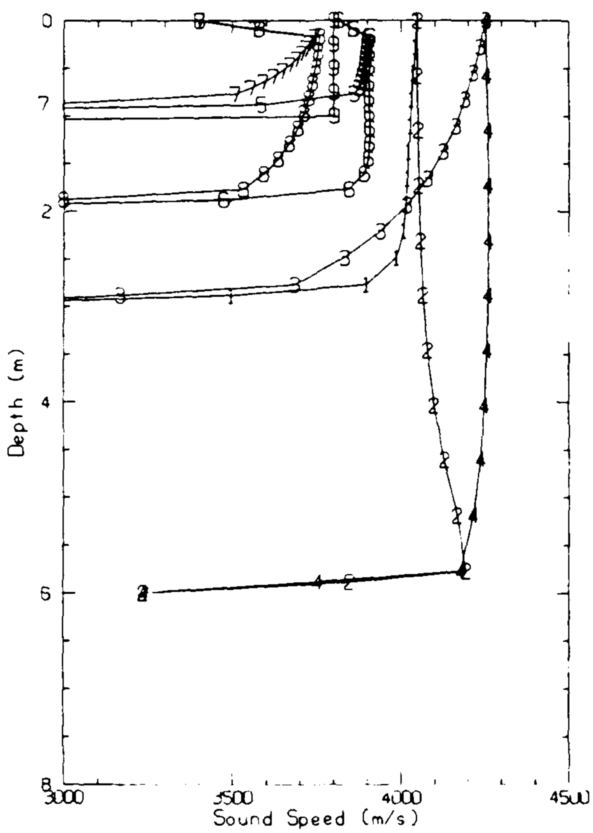

Figure 4. Sound speed profiles used for simulations. The following parameters for each SSP are given in the order of type of ice, thickness, and surface temperature: (1) multiyear, 3 m, −22.5°C; (2) multiyear, 6 m, −22.5°C; (3) multiyear, 3 m, −5°C; (4) multiyear, 6 m, −5°C; (5) first year, 1 m, −22.5°C; (6) first year, 2 m, −22.5°C; (7) first year, 1 m, −5°C; (8) first year, 2 m, −5°C; and (9) idealized profile with zero gradient in ice and water.

case is to be examined, the lowest frequency of 1 kHz is used, and no attenuation in the ice or water is assumed.

Comparison of the simulation results from both GSM and SAFARI show that the idealized zero-gradient SSP profile is the worst case, i.e., sound generated on the surface will propagate farther than in other cases and should be used as the guideline in placing noise measurement hydrophones. The rationale is that if a certain decrease in sound level can be realized with this SSP, then this range will also be more than adequate for all the other environmental conditions.

VI. APPLICATION

To make the result easier to use, two formulae were fitted to the pressure field obtained from the idealized SSP. The depth and the desired sound pressure level reduction were chosen as the independent variables to compute the deployment range. The formulae are shown below:

$$R = \frac{(d + 100)(44 + R_{50})}{150} - 44 \quad \text{for } d \le 50\text{ m} \tag{1}$$

and

$$R = \frac{(d - 50)(R_{100} - R_{50})}{150} + R_{50} \quad \text{for } 50\text{ m} < d < 100\text{ m}, \tag{2}$$

where

R = range to deploy the hydrophone, in meters

d = depth, in meters

$R_{50} = 0.00036\, a^{3.13}$

$R_{100} = 0.005\, a^{2.58}$

a = desired reduction in sound pressure level, in decibels.

The formulae are good for depths to 100 m and pressure level reductions of 40 to 80 dB relative to the source. A plot of the pressure contour lines computed from Eqs. (1) and (2) is shown in Figure 5. The actual contour lines for constant pressure levels as obtained from simulations are nonlinear. We chose to use two linear segments to approximate them in order to obtain simpler formulae. Note that at a fixed range, the formulae generally indicate a greater reduction in surface noise for shallower hydrophone depths.

At this point one might wonder if it isn't easier to deploy a hydrophone right underneath the camp at a deeper depth and rely on spherical spreading to attenuate the artificial noise. However, the simulation showed that the reduction in sound level relative to the source is 12 dB less than the amount caused by spherical spreading because of refractive focusing and air-ice interface reflection. To obtain a reduction of 60 dB right beneath the noise source, for example, a hydrophone would have to be deployed at a depth of almost 4000 m. To obtain the same reduction with the proposed formulae, a range of only 193 m is needed for a depth of 100 m, and an even shorter range of 132 m for a depth of 50 m. The standoff distance approach requires much less cable and is therefore preferred.

One drawback with the application of the formulae is that the level of the noise source is most likely unknown, and therefore the desired reduction is also unknown. One can always use the maximum reduction of 80 dB and, for example, obtain a range of 326 m for a deployment depth of 50 m or 276 m for a depth of 30 m. These ranges are realistic and would not pose much of a problem in deploying the surface cables.

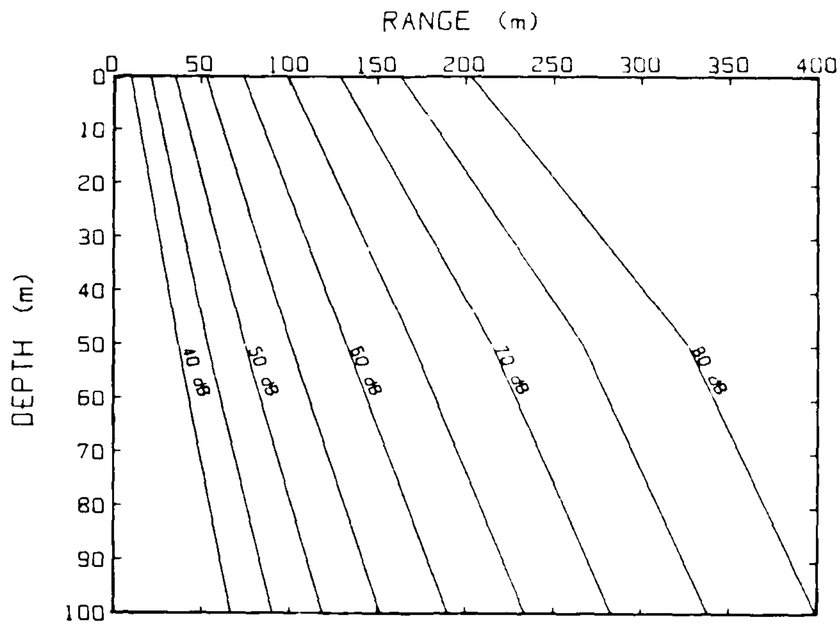

Figure 5. Sound pressure level contours obtained from the formulae. The numbers in decibels refer to the reduction from the source.

VII. SUMMARY

In this study we have shown that the worst possible location for an ambient noise measuring hydrophone is directly under an interfering source on the ice surface and that the best reduction in interference is gained by separating the hydrophone horizontally from the source and deploying it at a shallow depth.

We compared two sound propagation models, GSM and SAFARI, to measured short-range propagation data from a point source on the ice surface and found good agreement between the measurements and models, using the SSP for the ice and seawater that applied. Simulation runs were then made for longer ranges and different SSPs in the ice to represent a variety of environmental conditions. For the worst case SSP in the ice, simple formulae were developed that conservatively represent the sound field pressure reduction predicted by the models as a function of range and depth from the source on the ice surface. It is anticipated that these formulae will prove useful in designing and conducting acoustic experiments from an ice camp where surface activities generate potentially interfering noise.

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REFERENCES

1. H. Weinberg, "Generic Sonar Model," NUSC 5971D, Naval Underwater Systems Center, Newport, Rhode Island, 1985.

2. H. Schmidt, "SAFARI, Seismo-Acoustic Fast field Algorithm for Range-Independent environments, User's Guide," Rep. SR-113, SACLANT Undersea Research Center, San Bartolomeo, Italy, 1988.

3. H. Weinberg, "Application of ray theory to acoustic propagation in horizontally stratified oceans," *J. Acoust. Soc. Am.* *58*(1), 97–110, 1975.

4. W. M. Ewing, W. S. Jardetzky, and F. Press, *Elastic Waves in Layered Media,* McGraw-Hill, New York, 1957.

5. H. Schmidt and F. B. Jensen, "A full wave solution for propagation in multilayered viscoelastic media with application to Gaussian beam reflection at fluid-solid interface," *J. Acoust. Soc. Am. 77*, 813–825, 1985.

6. H. Schmidt and F. B. Jensen, "Efficient Numerical Solution Technique for Wave Propagation in Horizontally Stratified Ocean Environments," Rep. SM-173, SACLANT ASW Research Center, La Spezia, Italy, 1984.

7. G. Maykut, "Energy exchange over young sea ice in the central Arctic," *J. Geophys. Res. 83*(C7) 3646–58, 1978